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Cancer risk among Chernobyl cleanup workers in Estonia and Latvia, 1986–1998

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Two cohorts of Chernobyl cleanup workers from Estonia (4,786 men) and Latvia (5,546 men) were followed from 1986 to 1998 to investigate cancer incidence among persons exposed to ionizing radiation from the Chernobyl accident. Each cohort was identified from various independent sources and followed using nationwide population and mortality registries. Cancers were ascertained by linkage with nationwide cancer registries. Overall, 75 incident cancers were identified in the Estonian cohort and 80 in the Latvian cohort. The combined-cohort standardized incidence ratio (SIR) for all cancers was 1.15 (95% confidence interval (CI) = 0.98–1.34) and for leukemia, 1.53 (95% CI = 0.62–3.17; $n = 7$). Statistically significant excess cases of thyroid (SIR = 7.06, 95% CI = 2.84–14.55; $n = 7$) and brain cancer (SIR = 2.14, 95% CI = 1.07–3.83; $n = 11$) were found, mainly based on Latvian data. However, there was no evidence of a dose response for any of these sites, and the relationship to radiation exposure remains to be established. Excess of thyroid cancer cases observed may have been due to screening, the leukemia cases included 2 unconfirmed diagnoses, and the excess cases of brain tumors may have been a chance finding. There was an indication of increased risk associated with early entry to the Chernobyl area and late follow-up, though not statistically significant. Further follow-up of Chernobyl cleanup workers is warranted to clarify the possible health effects of radiation exposure.

Key words: neoplasms; incidence; cohort; Chernobyl; Estonia; Latvia; radiation effects

After the reactor accident at the Chernobyl nuclear power station in April 1986, ~600,000 persons from throughout the former Soviet Union were sent to the Chernobyl area for environmental cleanup and related activities.[1] The cleanup workers, also known as liquidators, remained in the area for an average of 3 months.[2] Although average radiation doses to these workers are now known to have been low, ~0.1 Gy, some workers received higher doses.[3,4] To assess cancer risks related to working in a radioactively contaminated area, cohort studies of cleanup workers in Belarus,[5] Ukraine,[6] the Russian Federation,[7] Lithuania,[8] Latvia[9] and Estonia[10] were initiated.

The first results on cancer incidence and cause-specific mortality of the Estonian Study of Chernobyl Cleanup Workers covered the period 1986–1993.[10] No significant increase in the incidence of any cancer was found; however, significant excess cases of suicide deaths were observed. To evaluate further the possible effect of radiation exposure on the incidence of leukemia and other cancers among Chernobyl cleanup workers, a Baltic cohort was established. Here we report the results from Estonia and Latvia.

Material and methods

The establishment of the Chernobyl cleanup worker cohort in Estonia has been described in detail.[2] In brief, the cohort was assembled in 1992 using multiple data sources, including the General Staff of Estonian Defence Forces, the former Estonian Chernobyl Radiation Registry, the Estonian Chernobyl Committee and the former Ministry of Social Welfare. The criterion for including a person in these sources was the possession of an official record documenting the person's Chernobyl service. The initial cohort consisted of 4,832 men who worked in the Chernobyl area (the 30-km zone around the Chernobyl Nuclear Power Station, and some surrounding territories), during 1986–1991.

The Latvian cohort was identified in 1993–1994 from several sources. The main source was the Chernobyl Registry, which was formed on the basis of the then existing Latvian part of the All-Union Chernobyl Registry in 1991 when the Chernobyl Medical Group at the State Clinical Hospital was organized. The Chernobyl Medical Group was responsible for (bi)annual routine medical check-ups of the cleanup workers, for their hospitalization (if necessary) and for assigning them into disability groups. The military reservists' lists and regional Health Departments were also used. The initial cohort in Latvia consisted of 5,860 men who worked in the Chernobyl area (the 30-km zone around the Chernobyl nuclear power station, and the surrounding territories including Komarin, Narodichi, Ovruch, Slavutich, Zeljonij Mys and Zyabrovka) during 1986–1991 and had an official record documenting their service.

In both Estonia and Latvia, female cleanup workers participated in construction work; however, their number was small and their data were not collected.

A questionnaire study was conducted among cleanup workers in Estonia in 1992–1993,[2] and in Latvia in 1993–1994 to collect information on Chernobyl service and risk factors for cancer. Dosimeter readings were assumed to approximate a whole-body dose, and were abstracted primarily from military lists and the questionnaire responses. In most cases, these doses were based on thermoluminescent dosimeters or film badges.

In both countries, the cohorts were followed through population, mortality and cancer registries. Each cleanup worker was followed for vital status from the date of return to his home country until death, emigration or December 31, 1998, whichever occurred first. In Estonia, 46 (1.0%) of the cleanup workers were excluded

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from the analysis because they could not be traced (43 persons) or the year of birth was unknown (3 persons). In Latvia, 314 (5.4%) men were excluded because they could not be traced. Thus, cancer incidence analysis was conducted for 4,786 cleanup workers from Estonia and 5,546 from Latvia for a total of 10,332 workers. Cancer cases diagnosed between 1986 and 1998 in the cohorts were identified by record linkage with the nationwide Estonian Cancer Registry and Latvian Cancer Registry. During 1993–1997, 81% of cancers among men from Estonia and 67% from Latvia were microscopically confirmed (excluding nonmelanoma skin cancers).[11] Cancer sites were classified according to the 9th revision of the International Classification of Diseases (ICD-9).[12] Histological type was classified according to the 2nd edition of the International Classification of Diseases for Oncology (ICD-O-2).[13]

The review of histological slides for available cases of malignant lymphoma in Estonia was performed by the late Dr. William Moloney (Brigham and Women's Hospital, Boston), who confirmed the diagnoses. The Latvian thyroid cancer and leukemia cases were reviewed by panels of pathologists and haematologists within the framework of a multinational case–control study.[14] Of the 11 cases diagnosed in Latvia that were reviewed with or without slides, there was agreement with all 6 thyroid carcinomas, 1 chronic myeloid leukemia and 1 acute erythroleukemia. One acute erythroleukemia case and 1 adult T-cell leukemia case were not confirmed because of insufficient information; 1 acute lymphoid leukemia can possibly be classified as acute myeloid leukemia. This evaluation examined only 5 of 7 Latvian leukemia cases included in the present study.

Calculation of person-years at risk began on the day of return of the cleanup worker to his home country and ended at emigration, death or on December 31, 1998, whichever occurred first. If the cleanup worker had been in the Chernobyl area more than once, the calculation of person-years started at the date of the first return. The expected numbers of incident cases of cancer were obtained by multiplying the number of age- and calendar year-specific person-years with the national age- and calendar year-specific cancer incidence rates for the respective male populations in 1986–1998. The observed and expected numbers were counted by 5-year age groups and 3 calendar periods (1986–1990, 1991–1995 and 1996–1998).

The standardized incidence ratio (SIR) was calculated as the ratio of observed to expected number of cases for the combined cohort and the 2 countries separately. The exact 95% confidence intervals (CIs) for the SIRs were calculated by assuming the Poisson distribution for the observed number of cases.

The SIRs were calculated for individual cancer sites/types defined by the ICD-9 3-digit level, and also separately for all tobacco-related cancers and alcohol-related cancers. The tobacco-related cancers included cancers of the oral cavity, oropharynx and hypopharynx (ICD-9 codes 140–146, 148), esophagus (150), pancreas (157), larynx (161), lung (162), bladder (188) and kidney (189). The alcohol-related cancer group included cancer of the oral cavity, oropharynx, hypopharynx and esophagus (ICD-9 codes 141–146 and 148–150), liver (155) and larynx (161).

Results

The combined cohort consisted of 10,332 men with 113,194 person-years of follow-up (mean length of follow-up, 11.0 years) (Table I). The cleanup workers had spent an average of 103 days in the Chernobyl area. Radiation doses were available for 82% of the workers, with mean and median doses of 10.9 and 9.6 cGy, respectively.

During the follow-up period, 75 incident cancer cases were observed *vs.* 64.3 cases expected in Estonia (SIR = 1.17, 95% CI = 0.92–1.46). In Latvia, the corresponding figures observed were 80 and expected were 69.5 in Latvia (SIR = 1.15, 95% CI = 0.91–1.43) (Table II).

In the combined cohort, the SIR for all cancers was 1.15 (95% CI = 0.98–1.34) and for leukemia, 1.53 (95% CI = 0.62–3.17). Statistically significant excess cases were apparent for thyroid (SIR = 7.06, 95% CI = 2.84–14.6) and brain cancer (SIR = 2.14, 95% CI = 1.07–3.83). The SIR was 1.16 (95% CI = 0.91–1.47) for tobacco-related cancers and 1.16 (95% CI = 0.73–1.77) for alcohol-related cancers. Of the 30 SIRs presented, 15 were above 1.0, 14 were below 1.0 and 1 was equal to 1.0. However, there were 4 statistically significantly increased SIRs and no significant deficits.

In Estonia, no statistically significant SIR was observed for cancer of any individual sites (Table II). No cases of leukemia were diagnosed, but only 1.8 were expected (SIR = 0.0, 95% CI = 0.0–2.0). The highest SIR was found for thyroid cancer (SIR = 3.88, 95% CI = 0.47–14.0), based on only 2 cases. The SIR was 1.12 (95% CI = 0.77–1.58) for tobacco-related cancers and 1.21 (95% CI = 0.60–2.16) for alcohol-related cancers.

In Latvia, there were statistically significant increases in risk of thyroid cancer (SIR = 10.52; 95% CI = 3.41–24.54) and leukemia (SIR = 2.59; 95% CI = 1.04–5.34), based on 5 and 7 cases, respectively. The SIR was 1.20 (95% CI = 0.85–1.64) for tobacco-related cancers and 1.13 (95% CI = 0.57–2.03) for alcohol-related cancers.

Overall, 7 thyroid cancers and 7 leukemia cases were observed (Table III). Four of the seven men with thyroid cancer arrived at Chernobyl in May 1986, *i.e.*, almost immediately after the accident when the potential for exposure to radioactive iodines was the highest. All men who developed thyroid cancer were over the age of 30 years (average, 36 years) at time of arrival at Chernobyl. Of the 7 leukemia cases, 2 were specified as chronic myeloid leukemia, 1 as acute myeloid leukemia, 2 as acute erythroleukemia (coded as unspecified acute leukemia for this analysis), 1 as acute lymphoid leukemia and 1 as unspecified lymphoid leukemia. Five leukemia cases were reported among men sent to Chernobyl in 1986.

In the combined cohort, there was an indication of increased SIR for thyroid cancer among cleanup workers who were sent to Chernobyl in April–May 1986, and for thyroid and brain cancers at follow-up of 10 or more years (Table IV). However, there was no indication of a dose–response relationship for any cancer, and workers with highest whole-body doses did not have increased incidence of cancer. For all cancers, the SIR was somewhat elevated among those arriving in Chernobyl in 1986 and among those who stayed 85 or more days. For cleanup workers from Latvia, who arrived in the area in 1986, the SIR for leukemia was 3.31 (95% CI = 1.07–7.71), whereas it was 1.68 (95% CI = 0.20–6.07) for those arriving after 1986. Among Latvian workers, the SIR for leukemia diagnosed less than 5 years after the return was 1.90 (95% CI = 0.23–6.87) as opposed to 3.90 (95% CI = 1.26–9.09) for leukemia diagnosed 5–9 years after return.

Discussion

More than 12 years after the Chernobyl accident, there was no statistically significant increase in overall cancer risk, but there was some indication of an excess of thyroid cancer cases, leukemia and brain cancer cases in the combined Estonian–Latvian cohort of 10,332 cleanup workers. As discussed below, however, the relationship of the apparent excess number of cases to radiation exposure remains unclear.

The validity of our data is strengthened by the study design, which included ascertainment of the cohort from multiple, overlapping sources, with documentation of service at Chernobyl required for inclusion in the cohort, and follow-up of the cohort through record linkage with nationwide population, mortality and cancer registries. The population-based cancer registries were established in both the countries well before the accident and their quality meets the criteria for international comparisons.[11] The weaknesses include potential biases associated with surveillance,

TABLE I – DISTRIBUTION OF MEN IN THE COHORTS OF CHERNOBYL CLEANUP WORKERS IN ESTONIA, LATVIA AND BOTH COUNTRIES BY SELECTED CHARACTERISTICS, 1986–1998

Characteristics	Estonia		Latvia		Combined cohort	
	No.	%	No.	%	No.	%
Age group (years)[1]						
≤19	78	1.6	80	1.4	158	1.5
20–29	1,838	38.4	2,160	38.9	3,998	38.7
30–39	2,298	48.0	2,602	46.9	4,900	47.4
40–49	539	11.3	633	11.4	1,172	11.3
≤50	33	0.7	71	1.3	104	1.0
Total	4,786	100	5,546	100	10,332	100
Person-years in an age group[2]						
≤19	57.6	0.1	52.5	0.1	110.1	0.1
20–29	8,855.3	17.1	10,678.2	17.4	19,533.5	17.3
30–39	24,206.8	46.8	28,382.9	46.2	52,589.7	46.5
40–49	16,001.8	30.9	18,938.2	30.8	34,940.0	30.9
≤50	2,617.5	5.1	3,402.9	5.5	6,020.4	5.3
Total	51,739.0	100	61,454.7	100	113,193.7	100
Time of arrival in the Chernobyl area						
1986 (April–May)	1,400	29.2	857	15.4	2,257	21.8
1986 (June–December)	1,503	31.4	2,167	39.0	3,670	35.5
1986 (month unknown)	21	0.4	0	–	21	0.2
1987–1991	1,745	36.4	2,522	45.4	4,267	41.2
Unknown	117	2.4	0	–	117	1.1
Duration of stay in the Chernobyl area (days)						
≤29	253	5.2	389	7.0	642	6.2
30–89	1,844	38.5	2,867	51.6	4,711	45.5
90–149	1,498	31.2	1,407	25.3	2,905	28.1
150–209	835	17.4	700	12.6	1,535	14.8
≥210	65	1.3	183	3.2	248	2.4
Unknown	291	6.0	0	–	291	2.8
Documented dose (cGy)						
≤4.9	1,097	22.9	844	15.2	1,941	18.7
5.0–9.9	1,271	26.5	1,311	23.6	2,528	24.9
10.0–14.9	700	14.6	579	10.4	1,279	12.3
15.0–24.9	942	19.6	1,608	28.9	2,550	24.6
≥25.0	28	0.5	48	0.8	76	0.7
Unknown[3]	748	15.6	1,156	20.8	1,904	18.4

[1]Age at beginning of follow-up.–[2]Men contributed person-years to several age groups, depending on their ages at the beginning and end of the study.–[3]It shows the number of men whose dose was not recorded in any source.

low statistical power associated with low and presumably imprecise individual recorded doses, relatively short follow-up time for most solid cancers and possible inaccurate diagnoses due to incomplete histologic verification.

In the interpretation of the findings, it is important to note that the small number of excess thyroid cancer cases observed is largely the result of screening examinations carried out among the cleanup workers in both the countries. Both thyroid cancers in the Estonian cohort, for example, were detected during thyroid examinations conducted on a sample of 1,984 cleanup workers in March–April 1995.[15] In Latvia, the majority of cleanup workers received, first, annual[16] and, later, biannual routine medical check-ups in outpatient clinics, and thus were under much closer medical surveillance than that of the general male population. Comparison with the general population that has not received similar examinations could produce spurious results. The effect of screening is difficult to quantify, since it depends on the methods used and the age and gender of the population. The significance of the thyroid cancer increase, however, disappears if the expected value of cases is multiplied by a factor of 3 to account for a screening effect as suggested by the National Council on Radiation Protection and Measurements.[17]

In addition to the likely effect of screening, the high risk is also inconsistent with what is known about the effect of age at exposure on thyroid cancer risk, *i.e.*, there is no evidence that radiation exposure to substantially higher doses (whether to γ-rays or radioiodines) to adult men over age 30 causes thyroid cancer.[18,19] Our analysis is based on recorded whole-body external doses, but not thyroid doses, and exposure to radioiodines within a few weeks after the accident might have been contributed to increased risk of thyroid cancer. Nonetheless, the exposures during this period are not likely to be substantial and the effect of exposure at adult age is likely to be small, if any.

Second, ascertainment bias stemming from increased awareness and medical attention may increase false-positive diagnoses of leukemia,[20,21] and hence explain the excess number of cases in the Latvian cohort. This is suggested by the anomalously high rate of erythroleukemia. In the Russian cleanup worker study, for example, a significant excess of leukemia cases have been reported in comparison with national rates, but not in a case–control study with internal comparison among cleanup workers that excluded unconfirmed diagnoses and chronic lymphocytic leukemia. The mean doses for cases were lower than those for controls, and there was no evidence for a dose response.[22–25] Similarly, there was no evidence of a dose response among our combined cohort, only 3 of the 5 leukemias evaluated were histologically confirmed, and one of the leukemias (adult T-cell) is caused by a virus and not radiation.[26]

Third, the size of the Latvian cohort (5,860 men) in our study is smaller than the maximum number (about 6,500 men) previously reported in the literature.[27] If correct, it is possible that up to 10% of Latvian cleanup workers may have been missed. This would leave open the possibility of differential ascertainment with more comprehensive identification of men with long-term diseases, including cancer, due to ascertainment through medical services. This also could result in an overestimation of risk. However, we have not yet been able to reconcile the differences in the cohort numbers, and so there is some uncertainty as to whether a potential problem exists in cohort definition.

TABLE II – NUMBER OF OBSERVED INCIDENT CASES AND STANDARDIZED INCIDENCE RATIO (SIR) IN THE COHORTS OF CHERNOBYL CLEANUP WORKERS IN ESTONIA, LATVIA AND BOTH COUNTRIES BY CANCER SITE OR TYPE, 1986–1998

ICD-9	Site or type	Estonia			Latvia			Combined cohort		
		Cases	SIR	95% CI	Cases	SIR	95% CI	Cases	SIR	95% CI
140–208	All sites or types	75	1.17	0.92–1.46	80	1.15	0.91–1.43	155	1.15	0.98–1.34
140–149	Mouth, pharynx	7	1.37	0.55–2.82	6	1.18	0.43–2.57	13	1.27	0.68–2.18
150	Esophagus	3	2.26	0.47–6.61	1	0.65	0.02–3.62	4	1.39	0.38–3.57
151	Stomach	8	1.05	0.45–2.06	8	0.90	0.39–1.78	16	0.96	0.55–1.57
152	Small intestine	0	0.00	0.00–29.94	1	8.08	0.20–45.04	1	4.05	0.10–22.57
153–154	Colon, rectum	4	0.77	0.21–1.98	6	1.24	0.45–2.70	10	0.99	0.48–1.84
155–159	Other digestive	4	1.15	0.31–2.93	2	0.42	0.05–1.51	6	0.72	0.27–1.58
160–161, 163–165	Nasal cavities, larynx, *etc.*	2	0.66	0.08–2.37	5	1.24	0.40–2.90	7	0.99	0.40–2.04
162	Lung	17	1.39	0.81–2.23	19	1.36	0.82–2.12	36	1.37	0.96–1.90
170–171	Bone, connective tissue	1	0.83	0.02–4.65	0	0.00	0.00–2.85	1	0.40	0.01–2.23
172	Skin (melanoma)	4	2.30	0.63–5.89	2	1.38	0.17–4.99	6	1.88	0.69–4.10
173	Skin (nonmelanoma)	4	1.02	0.28–2.61	1	0.26	0.01–1.43	5	0.63	0.21–1.49
175	Breast	0	0.00	0.00–54.87	0	0.00	0.00–28.11	0	0.00	0.00–18.59
185	Prostate	0	0.00	0.00–2.57	0	0.00	0.00–3.26	0	0.00	0.00–1.44
186	Testis	1	0.57	0.01–3.18	2	1.34	0.16–4.85	3	0.92	0.19–2.70
187–190	Penis, urinary bladder, *etc.*	3	0.50	0.10–1.47	7	1.11	0.44–2.28	10	0.81	0.39–1.50
191	Brain	6	2.39	0.88–5.20	5	1.90	0.62–4.44	11	2.14	1.07–3.83
192	Other CNS	0	0.00	0.00–18.61	0	0.00	0.00–19.74	0	0.00	0.00–9.58
193	Thyroid gland	2	3.88	0.47–14.02	5	10.52	3.41–24.54	7	7.06	2.84–14.55
194	Other endocrine	0	0.00	0.00–69.25	1	6.90	0.17–38.44	1	5.04	0.13–28.11
195–199	Site uncertain	1	0.76	0.02–4.23	0	0.00	0.00–4.40	1	0.46	0.01–2.58
200, 202	Non-Hodgkin's lymphoma	4	2.26	0.61–5.78	1	0.71	0.02–3.98	5	1.57	0.51–3.68
201	Hodgkin's disease	3	1.96	0.40–5.74	1	0.64	0.02–3.56	4	1.29	0.35–3.31
203	Multiple myeloma	1	2.45	0.06–13.67	0	0.00	0.00–6.26	1	1.00	0.03–5.59
204–208	Leukemia	0	0.00	0.00–1.99	7	2.59	1.04–5.34	7	1.53	0.62–3.17
204	Lymphoid leukemia	0	0.00	0.00–4.66	2	2.33	0.28–8.43	2	1.21	0.15–4.38
205	Myeloid leukemia	0	0.00	0.00–4.73	3	2.66	0.55–7.77	3	1.57	0.32–4.59
206	Monocytic leukemia	0	0.00	0.00–178.60	0	0.00	0.00–34.38	0	0.00	0.00–28.83
207	Other specified leukemia	0	0.00	0.00–107.72	2	4.45	0.54–16.08	2	4.13	0.50–14.94
208	Unspecified leukemia	0	0.00	0.00–16.55	0	0.00	0.00–22.93	0	0.00	0.00–9.61

TABLE III – SELECTED CHARACTERISTICS OF CASES OF THYROID CANCER AND LEUKEMIAS IN THE COHORTS OF CHERNOBYL CLEANUP WORKERS IN ESTONIA AND LATVIA, 1986–1998

Cancer site/type (ICD-9)[1]	Histological type (ICD-O-2)	Month and year of diagnosis	Age at diagnosis (years)	Date of entry to the Chernobyl area	Age at entry (years)	Duration of stay in the Chernobyl area (days)	Documented dose (cGy)[2]
Thyroid gland (193)	Papillary adenocarcinoma (8260.3)	June 1995	47	May 12, 1986	38	53	7.00
Thyroid gland (193)	Papillary adenocarcinoma (8340.3)	June 1995	44	May 10, 1986	35	149	3.50
Thyroid gland (193)	Papillary adenocarcinoma (8260.3)	Feb 1998	43	May 08, 1986	32	98	19.97
Thyroid gland (193)	Follicular carcinoma (8332.3)	Aug 1996	50	July 15, 1987	41	94	7.22
Thyroid gland (193)	Papillary cystadeno-carcinoma (8450.3)	Jan 1997	48	July 15, 1986	37	133	13.45
Thyroid gland (193)	Papillary cystadeno-carcinoma (8450.3)	March 1996	51	May 12, 1986	41	63	3.11
Thyroid gland (193)	Papillary adenocarcinoma (8260.3)	Oct 1998	41	Nov 20, 1986	29	66	20.49
Lymphoid leukemia (204.9)	Lymphoid leukemia, NOS (9820.3)	Jan 1995	40	Aug 30, 1986	32	51	14.00
Lymphoid leukemia (204.0)	Acute lymphoid leukemia (9821.3)	Jan 1995	51	July 16, 1986	43	101	4.10
Myeloid leukemia (205.1)	Chronic myeloid leukemia (9863.3)	June 1996	43	July 16, 1986	33	96	3.07
Myeloid leukemia (205.0)	Acute myeloid leukemia (9861.3)	June 1991	41	April 25, 1988	38	176	0.79
Myeloid leukemia (205.1)	Chronic myeloid leukemia (9863.3)	Nov 1994	47	Aug 21, 1986	39	57	19.08
Other leukemia (207.0)	Acute erythremic myelosis (9841.3)	June 1992	42	May 08, 1986	36	75	10.86
Other leukemia (207.0)	Acute erythremic myelosis (9841.3)	May 1990	43	Oct 26, 1987	40	57	2.03

[1]Two first cases of thyroid cancer were diagnosed among the cohort in Estonia; all other cases listed belong to the cohort in Latvia.–[2]The documented dose reflects an estimate of external exposure and is assumed to reflect the whole body dose.

TABLE IV – NUMBER OF OBSERVED INCIDENT CASES AND STANDARDIZED INCIDENCE RATIO (SIR) OF THYROID CANCER, LEUKEMIA, BRAIN CANCER AND ALL CANCERS IN THE COHORTS OF CHERNOBYL CLEANUP WORKERS IN ESTONIA AND LATVIA BY SELECTED CHARACTERISTICS, 1986–1998[1]

Characteristic	Thyroid cancer			Leukemia			Brain cancer[2]			All cancers		
	Cases	SIR	95% CI	Cases	SIR	95% CI	Cases	SIR	95% CI	Cases	SIR	95% CI
Year of arrival in the Chernobyl area												
1986	6	10.67	3.92–23.24	5	1.88	0.61–4.39	7	2.32	0.93–4.78	85	1.11	0.89–1.38
April–May 1986	4	18.10	4.93–46.37	1	0.99	0.03–5.54	3	2.52	0.52–7.39	37	1.23	0.87–1.71
June–December 1986	2	5.90	0.71–21.32	4	2.43	0.66–6.23	4	2.19	0.60–5.63	48	1.04	0.77–1.38
≥1987	1	2.39	0.06–13.34	2	1.08	0.13–3.92	4	1.94	0.53–4.97	69	1.23	0.96–1.57
Age at start of follow-up (years)												
<20	0	0.00	0.00–867.5	0	0.00	0.00–90.18	0	0.00	0.00–87.00	2	4.60	0.56–16.62
20–29	0	0.00	0.00–17.74	0	0.00	0.00–3.50	1	0.72	0.00–4.02	10	0.61	0.29–1.13
≥30	7	8.98	3.61–18.52	7	2.02	0.81–4.17	10	2.69	1.29–9.96	143	1.22	1.02–1.42
Duration of stay in the Chernobyl area (days)												
<85	3	6.40	1.32–18.72	4	1.76	0.48–4.53	4	1.61	0.44–4.15	64	0.97	0.75–1.25
≥85	4	8.13	2.22–20.84	3	1.39	0.29–4.08	7	2.79	1.12–5.75	89	1.40	1.13–1.73
Documented dose (cGy)[3]												
<9.6	4	9.58	2.61–24.54	4	2.31	0.63–5.92	6	2.88	1.06–6.28	68	1.28	1.00–1.63
≥9.6	3	8.00	1.65–23.38	3	1.71	0.35–5.00	3	1.49	0.31–4.36	57	1.22	0.93–1.59
Time since return from Chernobyl area (years)												
<5	0	0.00	0.00–11.63	2	1.07	0.13–3.90	1	0.55	0.01–3.10	37	0.93	0.66–1.29
5–9	4	8.37	2.28–21.45	5	2.40	0.78–5.62	5	2.10	0.68–4.92	84	1.28	1.02–1.59
≥10	3	15.27	3.15–44.63	0	0.00	0.00–5.93	5	5.16	1.68–12.06	34	1.18	0.82–1.66

[1]Column totals differ for the different categories because of missing values.–[2]Diagnostic confirmation of brain cancers at the cancer registries is as follows: glioblastoma, NOS (histological type by ICD-O-2 9440.3)—3 cases; malignant tumor, NOS (8000.3)—2 cases; malignant glioma (9380.3); anaplastic astrocytoma (9401.3); astrocytoma, NOS (9440.3); malignant meningioma (9530.3); brain cancer based on computer tomography—2 cases.–[3]The documented dose reflects an estimate of external exposure and is assumed to reflect the whole body dose.

Fourth, record linkage with death certificates (indicating the cause of death) in Latvia was based on manual procedures. This means that the lists with names and some additional identifiers of cleanup workers were compared visually with original death certificates. The same procedure is used for comparing and updating the files of the cancer registry. Manual record linkage may result in missing some of the death certificate cases and consequently underestimate cancer incidence both in the cohort and in the general population. However, we also undertook an analysis of proportional incidence ratios for this study population, and results showed general similarity with SIRs, thus suggesting lack of bias. Also, with the exception of leukemia and thyroid cancer, overall results for the Latvian and Estonia cohorts were quite similar.

Fifth, in 1992, when we were planning the study, there was uncertainty about the doses received by cleanup workers. It was expected that a combined analysis drawing on data for workers

from Estonia, Latvia, Lithuania and Belarus might include at least 20,000 cleanup workers. With a sample of this size, there would be 80% power to detect an excess of leukemia cases after 20 years of follow-up if the dose was 30 cGy and the relative risk was 2.2.[28] The on-going Lithuanian cohort study[8] was initially planned to be a part of joint efforts of all the 3 Baltic countries, but this goal has not yet been attained. Furthermore, it later turned out that the mean official radiation dose (recorded from military passports) was 11 cGy[2] and that a mean estimated whole-body dose from external radiation based on biological markers of exposure, *i.e.*, the fluorescence *in situ* hybridization technique of chromosomal translocation analyses and the glycophorin A locus *in vivo* somatic cell mutation assay was 10–11 cGy.[3,4] Thus the low statistical power to detect health effects of low-dose radiation,[29,30] and the imprecise recorded individual doses should be kept in mind when interpreting the results, particularly when considering dose–response relationships.

The adult brain is not considered to be particularly susceptible to the induction of cancer by ionizing radiation.[1] Most evidence of increased risk is for therapeutic irradiation occurring during childhood.[31–34] Although an increased risk of central nervous system tumors was apparent at lower doses among atomic bomb survivors, the dose response for gliomas was not statistically significant, though compatible with the overall estimate.[35] There is no evidence of any excess risk of brain cancer cases (shown as a part of the combined sites of eye, brain and other parts of central nervous system) among the cohort of cleanup workers from Russia for 1991–2001.[7] In a review of 10 cohort studies of US nuclear workers, a statistically significant increased death risk from brain cancers was found.[36] However, a similar increase in brain cancer risk was not demonstrated in the combined analysis of mortality among nuclear workers of the 3 countries[37] nor in recent studies of the nuclear workforce in Canada[38] and the nuclear industry in the United States.[39]

The excess of brain cancer cases in our study was of borderline significance, and it might be a chance finding due to multiple comparisons or close surveillance.[40] It also is possible that some of the brain cancers of ill-defined histology were metastatic from other primary sites. Although the SIR increased with time, it did not appear to be related to dose.

Long-term epidemiological monitoring of cancer risk among the Chernobyl cleanup workers with a cohort design is challenging and resource intensive, and so a nested case–control design has been used in Belarus, Russia and Baltic countries.[14] In Ukraine, the initial project[6] has taken a new shape, and leukemia risk currently is being investigated among ~110,000 cleanup workers, again employing a nested case–control approach.[41,42] In light of a recent publication,[43] the cohort study that was started in Belarus[5] seems to have stalled. The largest and most productive study based on the data of the Russian National Medical and Dosimetric Registry faces the enormous task of getting reliable information on the health status of 168,000–180,000 cleanup workers from 4,000 health care institutions spread across a very large area.[24,44] As yet, no results on cancer occurrence have emerged from the Lithuanian study.[8] In Latvia, the cancer registry is under immediate threat of closure, due to plans to create an integrated health information system for all diseases and for all purposes, and to collect only "non-sensitive" data.

Notwithstanding the hardships of trying to clarify the health consequences of Chernobyl, the international community has a deep collective interest in issues concerning the possible long-term health effects of the radiactive fallout.[1,45] Among other priorities, it is of utmost importance to ensure valid, long-term follow-up of the cohorts that have been formed. Unfortunately, in Estonia, all register-based public health research is threatened by the data protection law and its application.[46] The law carries the spirit of the 1990 and 1992 drafts of the European directive with a negative impact on research.[47–50] Thus, there exists a real threat of losing a tradition of epidemiological research in Estonia, which, though based on a relatively small population, has been of high quality. Under present circumstances, further follow-up of Chernobyl cleanup workers remains practically impossible.

Overall, no excess risk of cancer was found among Baltic Chernobyl cleanup workers, providing some assurances that radiation risks are low in these cohorts and not larger than those anticipated based on estimated doses. Some excess cases of cancer sites were observed, but may not be radiation-related: the excess of thyroid cancer cases was due largely to detection during special screenings; the excess of leukemia cases was not dose related, and several of the diagnoses were not confirmed; the excess of brain cancer cases also was not dose related and may be a chance finding. No significant associations between exposure characteristics and cancer risk were demonstrated, albeit based on small numbers.

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